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CLINICAL RESEARCH

CORONARY

A Clinical and Angiographic Scoring System to Predict the Probability of Successful First-Attempt Percutaneous Coronary Intervention in Patients With Total Chronic Coronary Occlusion

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ABSTRACT

OBJECTIVES This study sought to develop a scoring model predicting percutaneous coronary intervention (PCI) success in chronic total occlusions.

BACKGROUND Coronary chronic total occlusion is the lesion subtype in which angioplasty is most likely to fail. Chronic total occlusion for PCI (CTO-PCI) failure is associated with higher 1-year mortality and major adverse cardiac events compared with successful CTO-PCI. Although several independent predictors of final procedural success have been identified, no study has yet produced a model predicting final procedural outcome.

METHODS Data from 1,657 consecutive patients who underwent a first-attempt CTO-PCI were prospectively collected. The scoring model was developed in a derivation cohort of 1,143 patients (70%) using a multivariable stepwise analysis to identify independent predictors of CTO-PCI failure. The model was then validated in the remaining 514 (30%).

RESULTS The overall procedural success rate was 72.5%. Independent predictors of CTO-PCI failure were identified and included in the clinical and lesion-related score (CL-score) as follows: previous coronary artery bypass graft surgery +1.5 (odds ratio [OR]: 2.49, 95% confidence interval [CI]: 1.56 to 3.96), previous myocardial infarction +1 (OR: 1.6, 95% CI: 1.17 to 2.2), severe lesion calcification +2 (OR: 2.72, 95% CI :1.78 to 4.16), longer CTOs +1.5 (≥20 mm OR: 2.04, 95% CI: 1.54 to 2.7), non-left anterior descending coronary artery location +1 (OR: 1.56, 95% CI: 1.14 to 2.15), and blunt stump morphology +1 (OR: 1.39, 95% CI: 1.05 to 1.81). Score values of 0 to 1, >1 and <3, ≥3 and <5, and ≥5 identified subgroups at high, intermediate, low, and very low probability, respectively, of CTO-PCI success (derivation cohort: 84.9%, 74.9%, 58%, and 31.9%; $p < 0,0001$; validation cohort: 88.3%, 73.1%, 59.4%, and 46.2%; $p < 0.0001$).

CONCLUSIONS This clinical and angiographic score predicted the final CTO-PCI procedural outcome of our study population. (J Am Coll Cardiol Intv 2015;8:1540–8) © 2015 by the American College of Cardiology Foundation.

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Several studies have shown that successful percutaneous coronary intervention (PCI) for coronary chronic total occlusion (CTO) is associated with a better outcome in terms of reduced mortality and 1-year major adverse cardiac events compared with CTO-PCI failure (1-5).

Although new dedicated devices and guidewires have had a favorable impact on procedural success (6,7), CTO remains the type of lesion in which angioplasty is most likely to fail. In a multicenter study, Morino et al. (8), developed an angiographic scoring system to stratify CTO-PCI complexity. Recently, Nombela-Franco et al. (9) confirmed that the Japanese chronic total occlusion (J-CTO) score is a useful tool for predicting successful guidewire crossing of the CTO within 30 min, but they failed to demonstrate the value of such a model in predicting final procedural success. Although the predictive value of angiographic parameters has been thoroughly investigated, it has been recently reported that even clinical characteristics may have a predictive role (10,11).

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To obtain a scoring model able to predict final CTO-PCI success, we prospectively analyzed a cohort of patients who underwent CTO-PCI, taking into account both clinical and angiographic parameters.

METHODS

We analyzed 1,671 consecutive patients with CTO treated by PCI from January 2004 to December 2013. All patients provided written informed consent. The study protocol was approved by the local ethics committee, and all procedures were performed according to current international guidelines (12,13).

We reviewed the database of the 1,671 patients who underwent CTO-PCI procedures at ICPS (Massy and Quincy hospitals, France).

DEFINITIONS AND PATIENT SELECTION. A CTO was defined by angiography as a coronary occlusion without antegrade filling of the distal vessel other than via collaterals. The duration of the occlusion had to be more than 3 months, as estimated from the onset of clinical events including myocardial infarction (MI), sudden onset or worsening of chest symptoms, or evidenced by angiography. When the duration of the occlusion was uncertain, and the investigators had no clear evidence that it was <3 months, the patient was included in the analysis.

Quantitative assessment was performed using the Quant-Cor QCA software package (CAAS II, V.5.0, Pie Medical Imaging, Maastricht, the Netherlands).

Previous MI was defined as an MI (non-ST-segment elevation MI or ST-segment elevation myocardial infarction) with a culprit lesion other than the CTO or an MI that had occurred at least 3 months before the CTO-PCI.

Previous coronary artery bypass graft surgery (CABG) was defined as a previous CABG of the CTO vessel carried out at least 3 months before the CTO-PCI procedure.

Blunt morphology of the lesion: the lesion was classified as a blunt morphology type if the occluded segment did not end in the shape of a funnel.

Calcified lesions: presence of calcification was classified according to 3 categories—mild, moderate, and severe.

The measurement of the degree of retrograde collateral supply was performed using a collateral grading system, according to the Rentrop classification (14).

Bending lesion: this was defined as any lesion with at least 1 bend of >45° assessed by angiography along the whole length of the occluded segment.

Length of occlusion: occlusion length was categorized as either <20 or ≥20 mm according to the EuroCTO Club consensus (15).

Successful procedure was defined as the achievement of <30% residual diameter stenosis as assessed by quantitative coronary angiography and associated with Thrombolysis In Myocardial Infarction flow grade 3.

To improve the accuracy of lesion analysis, all cases were reviewed by our core laboratory before and after the procedure.

PATIENT SELECTION. Patients in whom CTO-PCI was attempted in the setting of acute cardiogenic shock were excluded. In addition, to minimize confounders, only the first CTO-PCI attempts performed during the enrolling period were included in the analysis. If 2 or more CTO PCIs were attempted during the same procedure, the patient was excluded. If a single CTO lesion or 2 different CTO lesions were attempted in 2 or more separate procedures during the enrolling period, only the first procedure was considered as a first attempt and subsequently included in the analysis.

DEFINITION OF COMPLICATIONS. MI was defined as >3 times the upper limit of normal creatine phosphokinase release, in the absence of escalating creatine phosphokinase before PCI.

Ostial dissection and major pericardial effusion were defined, respectively, as angiographic evidence

ABBREVIATIONS AND ACRONYMS

CABG = coronary artery bypass graft surgery

CI = confidence interval

CL-score = clinical and lesion-related score

CTO = chronic total occlusion

CTO-PCI = chronic total occlusion for percutaneous coronary intervention

J-CTO = Japanese chronic total occlusion score

LAD = left anterior descending coronary artery

MI = myocardial infarction

OR = odds ratio

PCI = percutaneous coronary intervention

of significant staining of medium contrast in subintimal strata of the coronary wall involving the coronary ostium and pericardial effusion requiring pericardiocentesis.

STATISTICAL ANALYSIS. Continuous variables were presented as mean ± SD or median (25th to 75th percentiles) according to distribution. Categorical variables were expressed as absolute numbers and percentages. Chi-square test was applied to evaluate the association between qualitative variables. The Student *t* test was used to compare quantitative variables between the 2 groups. A predictive score was developed on the basis of a derivation set of 1,143 randomly selected patients (70%). The score was then validated in the remaining 514 patients (30%; validation cohort). In the derivation cohort, a backward stepwise multivariable logistic regression was used to select a set of independent predictive variables. Independent variables were then scored according to the corresponding odds ratio (OR). The score validation was performed by logistic regression analysis of the validation cohort. Comparison of the success rates among score classes was also performed with a chi-square test for trend. A receiver-operating characteristic curve analysis was performed to compare the predictive impact of the new score with that of the J-CTO score.

To assess whether technical changes and improvement during the study period had an impact on our predictive variables, procedures were classified in chronological order and divided into 2 subgroups according to the procedural period: group A (January 2004 to December 2010) and group B (January 2011 to December 2013).

RESULTS

Between January 2004 and December 2013, 14 operators performed 1,833 CTO-PCI procedures in 1,671 patients of whom 14 were excluded because CTO-PCI was attempted in the setting of cardiogenic shock. A total of 1,657 patients with 1,657 first CTO-PCI attempts were enrolled. Procedural success was achieved in 1,202 of 1,657 procedures, accounting for an overall success rate of 72.5%.

BASELINE POPULATION. The baseline characteristics of the 1,657 study patients are reported in Table 1.

The median age of the population was 64 years; 27% of patients had diabetes, and 21.2%, 37.7%, and 7.5% had prior MI, prior PCI, and prior CABG, respectively. The most common indication for PCI was stable angina (56.3%), and the majority of patients had multivessel disease (55.9%).

TABLE 1 Baseline Characteristics of the Overall Population of "First Intention" PCI (N = 1,657)

Age, yrs	64 ± 11.1
Female	257 (15.5)
BMI, kg/m^2	27.3 ± 4.1
Hypertension	995 (60)
Dyslipidemia	1,042 (63)
Diabetes	484 (29.2)
Smoking	451 (27.2)
Previous MI	352 (21.2)
Previous PCI	625 (37.7)
Previous stroke	21 (1.3)
Previous CABG	124 (7.5)
LVEF <40%	253 (15.2)
Stable angina	934 (56.3)
IV class CKD	7 (0.4)
Multivessel CAD	926 (55.9)
Lesion-related characteristics	
CTO site	
LAD	506 (30.5)
RCA	764 (46.1)
LCX	381 (23)
LM	6 (0.4)
Ostial CTO	59 (3.6)
Blunt stump	889 (53.6)
Tortuous	251 (15.1)
Calcified lesion	943 (56.8)
Mild	483 (29.1)
Moderate	299 (18)
Severe	161 (9.7)
Lesion length ≥20 mm	580 (35)
Lesion length, mm	20.2 ± 21.1
Rentrop class 3	732 (44.1)
In-stent CTO	166 (10)
J-CTO score	1.62 ± 0.89
Procedural characteristics	
Radial access	1,092 (65.9)
Retrograde approach	154 (9.3)
Contralateral injection	600 (36.2)
Procedural time, min	87.3 ± 49.1
Total medium contrast amount, ml	259 ± 155
Monorail balloon support	95 (5.7)
Coaxial balloon support	369 (22.5)
Microcatheter support	849 (51.2)
Parallel wire	279 (16.8)
Anchor balloon	151 (9.1)
Anchor wire	100 (6)
Rotational atherectomy	25 (1.5)
Tornus	35 (2.1)

Values are mean ± SD, or n (%).

BMI = body mass index; CABG = coronary artery bypass graft surgery; CAD = coronary artery disease; CKD = chronic kidney disease; CTO = chronic total occlusion; J-CTO = Japanese chronic total occlusion score; LAD = left anterior descending coronary artery; LCX = left circumflex coronary artery; LM = left main; LVEF = left ventricular ejection fraction; MI = myocardial infarction; PCI = percutaneous coronary intervention; RCA = right coronary artery.

The right coronary artery was the most common site of CTO (46.1%), followed by the left anterior descending coronary artery (LAD) (30.5%), circumflex (23.0%), and left main (0.4%); 56.8% of lesions were calcified, 15.1% were tortuous, and 35.0% were long (≥20 mm). Class 3 Rentrop collateralization was reported in 44.1% of cases.

The majority of procedures were transradial (65.9%) and were carried out via an anterograde approach (90.6%). Contralateral injection was performed in 36.2% of patients. Attempts at achieving guidewire support were made using a microcatheter in the majority of cases (51.2%), followed by a coaxial balloon (22.5%) and by a monorail balloon (5.7%). The mean J-CTO score was 1.62 ± 0.89.

TABLE 2 Clinical and Lesion-Related Characteristics in the Derivation and Validation Groups

	Derivation Set (n = 1,143)	Validation Set (n = 514)	p Value
Age, yrs	63.7 ± 11.5	64.7 ± 11	0.93
Female	15.6	15.5	0.96
BMI, kg/m^2	27.5 ± 4	27.1 ± 4.4	0.81
Hypertension	60.9	58.4	0.34
Dyslipidemia	63.9	60.9	0.24
Diabetes	28.4	30.9	0.31
Smoking	25.7	30.9	0.027
Previous MI	20.7	22.4	0.47
Previous PCI	36.4	40.7	0.11
Previous stroke	1.4	1.2	0.81
Previous CABG	7.4	7.6	0.91
LVEF <40%	15.8	14	0.13
Stable angina	57	55.1	0.47
IV class CKD	0.4	0.4	0.88
Multivessel CAD	56.4	58.1	0.60
Lesion-related characteristics			
CTO site			
LAD	30.1	31.5	0.56
RCA	47.9	44.2	0.21
LCX	21.7	23.7	0.36
LM	0.3	0.6	0.31
Ostial CTO	3.7	3.3	0.71
Blunt stump	52	54.6	0.31
Tortuous	15	16.2	0.53
Calcified lesion			
Mild	30	28.6	
Moderate	18.5	17.8	0.73
Severe	9.3	11.2	0.22
Lesion length ≥20 mm	34.6	37.6	0.24
Lesion length, mm	20 ± 22.9	20 ± 16.3	0.56
Rentrop class 3	44.1	47.9	0.16
In-stent CTO	10.5	9.2	0.42
J-CTO score	1.63 ± 89	1.59 ± 0.89	0.29
Procedural success	72.4	73	0.53

Values are mean ± SD or %.
Abbreviations as in Table 1.

TABLE 3 Univariable Analysis: Clinical and Lesion-Related Characteristics According to Procedural Outcome of the Derivation Subgroup

	Failure (n = 316)	Success (n = 827)	p Value
Age, yrs	65.1 ± 11.9	63.5 ± 11.4	0.1
Female	15.2	15.6	0.86
BMI, kg/m^2	28 ± 4.4	27.3 ± 3.9	0.024
Hypertension	61.1	60.1	0.051
Dyslipidemia	69.3	61.8	0.018
Diabetes	30.4	27.7	0.36
Smoking	28.6	24.6	0.16
Previous MI	27.8	18	<0.0001
Previous PCI	44.3	33.4	0.001
Previous stroke	1.3	1.2	0.93
Previous CABG	12.3	5.6	<0.0001
LVEF <40%	15.8	15.8	0.73
Stable angina	52.2	58.8	0.045
IV class CKD	0.3	0.5	0.70
Multivessel CAD	59.9	55.1	0.15
Lesion-related characteristics			
CTO site			
LAD	20.9	33.6	<0.0001
RCA	47.9	44.2	0.17
LCX	24.7	20.6	0.13
LM	0.6	0.1	0.13
Ostial CTO	4.1	3.5	0.62
Blunt stump	62.1	51.5	0.001
Tortuous	19.4	13.3	0.01
Calcified lesion			
Mild	30.4	29.8	0.83
Moderate	21.8	17.3	0.08
Severe	16	6.7	<0.0001
Lesion length ≥20 mm	47.2	29.9	<0.0001
Lesion length, mm	24.7 ± 20.3	18.2 ± 23.5	<0.0001
Rentrop class 3	46.3	43.3	0.37
In-stent CTO	101.6	10.1	0.46

Values are mean ± SD or %.
Abbreviations as in Table 1.

Each patient was randomly assigned to the derivation cohort (70%, 1,143 patients), or to the validation cohort (30%, 514 patients). Except for smoking, no significant differences in terms of clinical and lesion-related characteristics were reported between the 2 groups (Table 2).

DERIVATION MODEL UNIVARIABLE ANALYSIS. The derivation cohort was divided according to procedural outcome, and clinical and lesion-related characteristics were analyzed (Table 3). Patients in whom CTO-PCI failed had a significantly higher body mass index (28.0 ± 4.4 vs. 27.3 ± 3.9; p = 0.024), higher incidence of dyslipidemia (69.3% vs. 61.8%; p = 0.018), more frequent history of MI (27.8% vs. 18.0%; p < 0.0001), PCI (44.3% vs. 33.4%; p = 0.001), and coronary artery bypass surgery (12.3% vs. 5.6%;

TABLE 4 Multivariable Analysis

	Overall Population Univariable Analysis			Stepwise Logistic Regression p < 0.0001		
	Failure (n = 316)	Success (n = 827)	p Value	Odds Ratio	95% CI	p Value
Dyslipidemia	69.3	61.8	0.018			
BMI, kg/m^2	28 ± 4.4	27.3 ± 3.9	0.024			
Previous MI	27.8	18	<0.0001	1.603	1.172–2.192	0.003
Previous PCI	44.3	33.4	0.001			
Previous CABG	12.3	5.6	<0.0001	2.491	1.566–3.963	<0.0001
Stable angina	52.2	58.8	0.045			
n-LAD	79.1	66.4	<0.0001	1.566	1.140–2.152	0.006
Blunt stump	51.5	62.1	0.001	1.390	1.051–1.813	0.028
Severe calcification	16	6.7	<0.0001	2.725	1.782–4.167	<0.0001
Lesion length ≥20 mm	47.2	29.9	<0.0001	2.044	1.547–2.70	<0.0001
Tortuous	19.4	13.3	0.01			

Values are % or mean ± SD.

CI = confidence interval; n-LAD = non-left anterior descending coronary artery; other abbreviations as in Table 1.

p < 0.0001) Stable angina was a less frequent indication of CTO-PCI in patients in whom PCI was unsuccessful (52.2% vs. 58.8%; p = 0.045).

Concerning lesion-related variables, nonrevascularized lesions were less frequently located in the LAD (20.9% vs. 33.6%; p < 0.0001), more often had a blunt stump (62.1% vs. 51.5%; p = 0.001), and were tortuous (19.4% vs. 13.3%; p = 0.01), severely calcified (16% vs. 6.7%; p < 0.0001), and longer (≥20 mm: 47.2% vs. 29.9%; p < 0.0001).

MULTIVARIABLE ANALYSIS. Using a backward stepwise approach, severe lesion calcification (OR: 2.72; 95% confidence interval [CI]: 1.78 to 4.16; p < 0.0001), previous CABG (OR: 2.49; 95% CI: 1.56 to 3.96; p < 0.0001), lesion length ≥20 mm (OR: 2.04; 95% CI: 1.54 to 2.70; p < 0.0001), previous MI (OR: 1.60, 95% CI: 1.17 to 2.19; p = 0.003) non-LAD location of the lesion (OR: 1.56, 95% CI: 1.14 to 2.15; p = 0.006), and blunt morphology of the lesion (OR: 1.39; 95% CI: 1.05 to 1.81; p = 0.028) were all independent predictors of unsuccessful CTO-PCI (Table 4).

TABLE 5 Independent Predictive Variables Scored According to OR

	OR	Score
Severe calcified lesion	2.72	+2
Previous CABG	2.49	+1.5
Lesion length ≥20 mm	2.04	+1.5
Previous MI	1.60	+1
Blunt stump	1.39	+1
Non-LAD CTO location	1.56	+1

OR = odds ratio; other abbreviations as in Table 1.

PREDICTIVE SCORE. Independent predictors of unsuccessful CTO-PCI were scored according to the corresponding OR size (Table 5). Four subgroups were identified on the basis of the success rate: score values of 0 to 1 (class 0), >1 and <3 (class 1), ≥3 and <5 (class 2), and ≥5 (class 3) corresponding to high, intermediate, low, and very low probability, respectively, of CTO-PCI success in the derivation cohort (p < 0.0001) (Figure 1). According to our score ranking, the probability of CTO-PCI failure increased significantly from class 0 to class 1 (15.1% to 25.1%; p = 0.0004), from class 1 to class 2 (25.1% to 41.1%; p < 0.0001), and from class 2 to class 3 (41.1% to 68.1%; p = 0.0005), respectively.

VALIDATION MODEL ANALYSIS. The predictive score was then applied to the validation cohort. The CL-score was also shown to be a strong predictor of final procedural success in the validation cohort (88.3%, 73.1%, 59.4%, and 46.2% in classes 0 to 3, respectively; chi-square for trend: p < 0.0001). In a logistic regression, the ORs of class 1 to 3 with respect to class 0 were: 2.78 (95% CI: 1.53 to 5.0), 5.15 (95% CI: 2.8 to 9.3), and 8.78 (95% CI: 3.5 to 21.7), respectively (all p values were <0.0001).

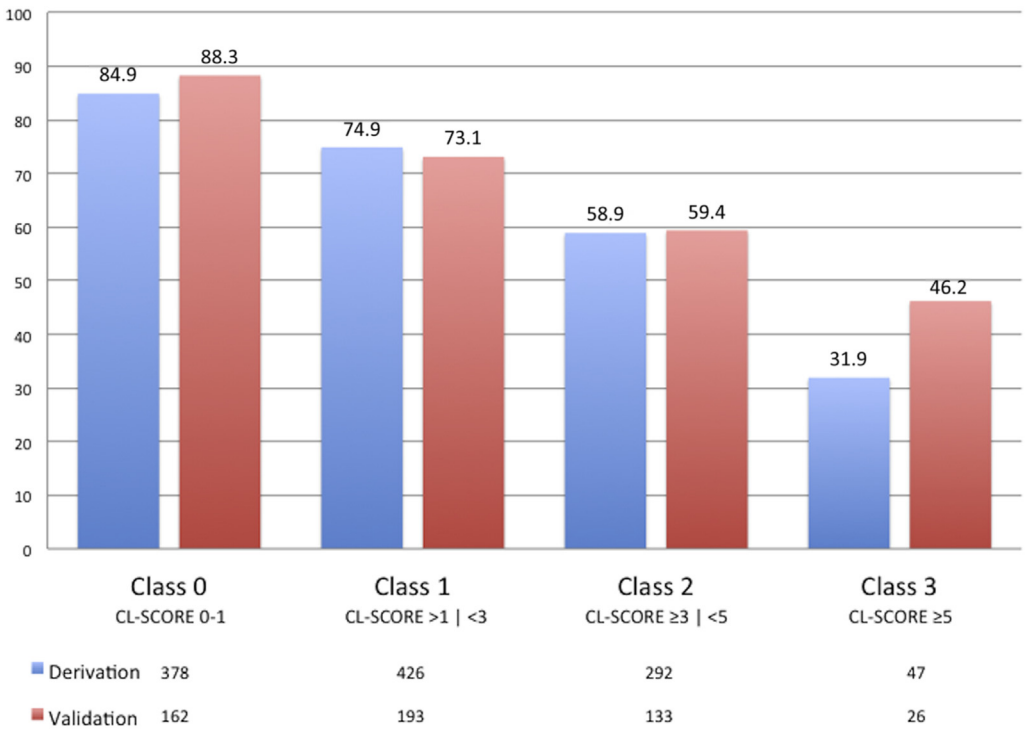
A receiver-operating characteristic curve analysis of the clinical and lesion-related score (CL-score) versus J-CTO score carried out in the validation cohort demonstrated the superior performance of the CL-score: area under the curve 0.68 (95% CI: 0.63 to 0.73) versus area under the curve 0.60 (95% CI: 0.54 to 0.65), respectively (Figure 2).

SAFETY ENDPOINT. The complication rate was low. No periprocedural deaths were recorded (<24 h). Post-procedural MI was reported in 34 patients (2%). Ostial dissection and pericardiocentesis were reported in 17 (1.0%) and 20 (1.3%) patients, respectively (Table 6). Patients who experienced coronary ostium dissection were all asymptomatic and did not require any surgical treatment. Two of 20 patients with pericardiocentesis required surgical pericardial drainage.

SUBGROUP ANALYSIS. Our population was divided into 2 subgroups according to the date of the procedure. Group A (n = 1,066) and group B (n = 591) included patients who underwent CTO-PCI between January 2004 and December 2010, and between January 2011 and December 2013, respectively (Figure 3).

The impact of the subgroup variable on final procedural success was found to be statistically significant (group A, 70.8%; group B, 75.6%; p = 0.036). Mean J-CTO score of group A was not statistically different compared with group B (1.59 ± 0.88 vs. 1.62 ± 0.89; p = 0.27).

FIGURE 1 Procedural Success Rate According to CL-Score Value in the Derivation and Validation Groups



Relationships between the 4 classes based on the clinical and lesion-related score (CL-score) value and probability of final procedural success in the derivation and validation groups. The CL-score was a strong predictor of final procedural success in both the validation and derivation cohorts.

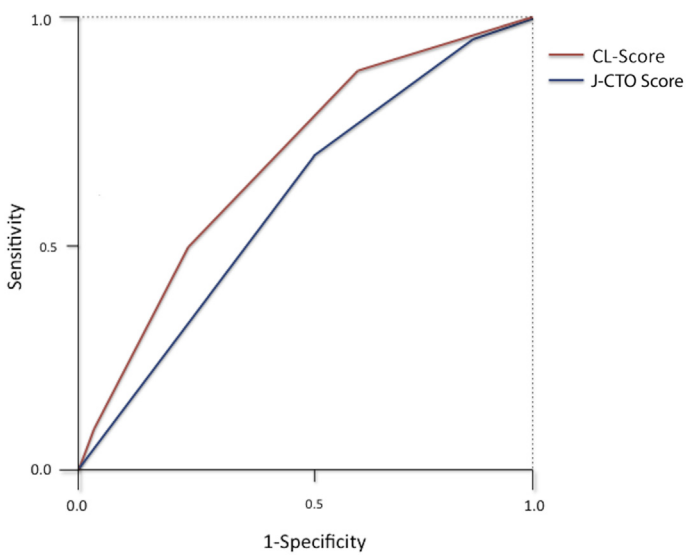
As expected, the availability of new dedicated devices changed the operators' approach to CTO-PCI during the enrolling period (Table 7). In group B, a larger proportion of transradial procedures (73% vs. 62%; $p < 0.001$), retrograde approach (15.4% vs. 6.0%; $p < 0.0001$), and concomitant collateral injection (50.2% vs. 28.4%; $p < 0.0001$) was performed. Coaxial (32.4% vs. 3.9%; $p < 0.0001$) and monorail balloon (7.9% vs. 1.8%; $p < 0.0001$) support and parallel wire techniques (19.6% vs. 14.4%; $p = 0.001$), frequently implemented in group A, were substituted by use of the microcatheter in the second part of the study (32.1% vs. 85.6%; $p < 0.0001$). The Tornus microcatheter (Asahi Intecc, Nagoya, Japan) was more frequently used in the first part of the study (2.8% vs. 0.8%; $p = 0.008$). No differences in the use of rotational atherectomy, anchor wire, or anchor balloon technique were reported. In group B, a significant reduction in the myocardial infarction rate was observed (0.8% vs. 2.7%, $p = 0.01$). On the other hand, a significant increase in the rate of coronary ostium dissection was reported in group B compared with group A (2.5% vs. 0.2%; $p = 0.0001$). No difference in pericardiocentesis was observed between the groups.

DISCUSSION

The score system presented here (CL-score) was developed on the basis of a prospective single-center study of 1,657 patients who underwent a first CTO-PCI attempt. To the best of our knowledge, this is the first predictive model of final procedural CTO-PCI success including both clinical and angiographic variables.

Notwithstanding the significant increase in success rates up to more than 85% to 90% reported by the majority of recent studies, especially in patients treated using the retrograde or hybrid approach (16,17), CTO is still the setting in which PCI is associated with the highest probability of failure. Previously reported studies have already underlined the impact of several lesion-related characteristics on the procedural outcome (18–23). More recently, calcification, bending, blunt stump, occlusion length ≥20 mm, and prior failed attempts were included in the J-CTO validated score as predictors of probability of

FIGURE 2 ROC Curve for Probability of Successful CTO-PCI According to CL-Score and J-CTO Score



Receiver-operating characteristic (ROC) analysis of the CL-score versus J-CTO score carried out in the validation cohort demonstrated the superior performance of the CL-score. The area under the curve was 0.68 for the CL-score and 0.60 for the J-CTO score. CL-score = clinical and lesion-related score; CTO-PCI = chronic total occlusion for percutaneous coronary intervention; J-CTO score = Japanese chronic total occlusion score.

guidewire crossing and predictors of longer procedural time (8,9). In addition, clinical variables have been shown to have a negative impact on final procedural success as reported in the most recent CTO-PCI series even when the hybrid approach was implemented (11,24,25).

In the study reported here, 2 clinical variables (history of CABG and history of MI), and 4 lesion-related variables (blunt stump, lesion calcification, non-LAD CTO, and lesion length ≥20 mm) were identified as independent predictors of unsuccessful CTO-PCI. Given that only first-attempt CTO-PCIs were included in the study, the majority of these procedures were performed via the antegrade approach. In instances where the antegrade approach failed, a new procedure was generally attempted via the retrograde approach. The fact that second attempts did not meet the inclusion criteria may account for the low rate of retrograde approach in our study. This, along with the low rate of contralateral injection and the relatively long enrollment period, may explain the relatively low success rate observed in our population.

TABLE 6 Events Reported in the Periprocedural Period (<24 h After CTO-PCI)

Death	(0)
MI	34 (2.0)
Ostial dissection	17 (2.8)
Pericardiocentesis	20 (1.3)

Values are n (%).
CTO-PCI = chronic total occlusion for percutaneous coronary intervention; MI = myocardial infarction.

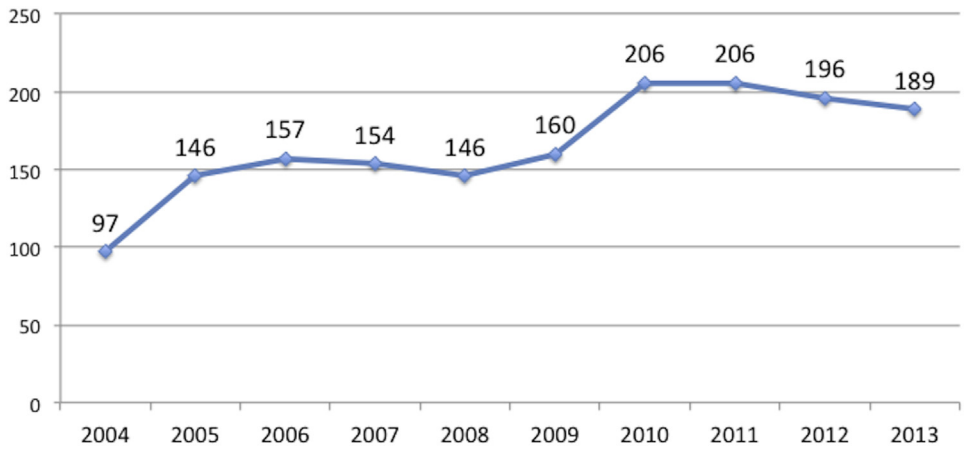
A subgroup analysis was carried out to compare procedures performed in the first period (group A) and in the second period (group B) to minimize the impact of newly available devices on final procedural success during the enrolling period. The higher success rate observed in the second part of the study suggested a favorable impact of new dedicated devices and increasing experience on the final procedural success rate. In addition, the increased incidence of coronary ostium dissection in group B was not clinically relevant (no need for surgical treatment and spontaneous resolution), whereas a significant reduction in post-procedural MI was observed in the second part of the enrolling period.

The effect of operator expertise on procedural success was also taken into account. Consensus reports on CTO management specify that patients scheduled for CTO-PCI should be referred to a skilled operator. Although a minimum of 75 CTO-PCIs per operator has been considered a reasonable threshold to identify a skilled operator (26), no definite cutoff value has yet been validated. Although the operators involved in the study had varying degrees of expertise, all of them were, nevertheless, skilled operators. Extrapolation analysis of data pertaining to 2 highly experienced CTO-PCI operators (>300 CTOs each in this study) who performed CTO-PCIs from 2010 to 2013 (213 procedures, contralateral injection 60%, retrograde approach 21%) showed an 87.8% success rate.

An increasing number of operators and centers are currently building up CTO PCI expertise owing to the availability of new dedicated devices, techniques, and training courses organized by expert operators and to mounting evidence of the benefits of CTO revascularization compared with medical therapy (25,27).

Given that the present predictive CL-score was mainly established on the basis of CTO-PCIs attempted via the antegrade approach, it seems to be applicable in contemporary settings, especially in centers where the retrograde/hybrid approach has not yet been adopted. Pre-procedural assessment of the probability of success may support the decision to attempt PCI in a CTO lesion or to refer the patient to a high-volume CTO-PCI center where the hybrid/

FIGURE 3 Annual Distribution of First-Intention CTO-PCI Procedures



Annual distribution of first attempt CTO-PCI performed during the 10-year enrolling period at our center. CTO-PCI = chronic total occlusion for percutaneous coronary intervention.

retrograde approach is performed. This particularly applies to patients with a high CL-score, especially those with chronic renal insufficiency, mild angina (low Canadian Cardiovascular Society classes), or a modest amount of ischemic burden.

STUDY LIMITATIONS. A few limitations of this analysis should be taken into account. 1) Given that this score system was developed from data collected in a study carried out in a single center on first-attempt CTO-PCI procedures mainly performed via the antegrade approach with a high proportion of experienced operators, our predictive model cannot be automatically extrapolated to settings with a different level of operator experience, previously attempted procedures, or a different procedural algorithm. 2) Another limitation of our study is the absence of anatomic evaluation by an external core laboratory. 3) Other clinical variables, such as the degree of renal impairment, could have a predictive impact. 4) As the techniques and CTO-specific medical technologies are evolving, the score will require updating in the future.

TABLE 7 Procedural Characteristics of Groups A and B

	Group A (n = 1,066)	Group B (n = 591)	p Value
Femoral access	405 (38.0)	160 (27.0)	<0.0001
Retrograde approach	64 (6.0)	91 (15.4)	<0.0001
Contralateral injection	303 (28.4)	297 (50.2)	<0.0001
Procedural time, min	87.3 ± 46.9	87.5.4 ± 52.6	0.9
Contrast amount, ml	269 ± 164.6	243 ± 137.9	0.002
Monorail balloon support	84 (7.9)	11 (1.8)	<0.0001
Coaxial balloon support	346 (32.4)	23 (3.9)	<0.0001
Microcatheter support	343 (32.1)	506 (85.6)	<0.0001
Parallel wire	150 (19.6)	129 (14.4)	0.0062
Anchor balloon	96 (9.0)	56 (9.5)	0.46
Anchor wire	71 (6.6)	29 (4.9)	0.14
Rotational atherectomy	17 (1.6)	8 (1.3)	0.7
Tornus	30 (2.8)	5 (0.8)	0.008
Final success	755 (70.8)	447 (75.6)	0.036
MI	29 (2.7)	5 (0.8)	0.01
Ostial dissection	2 (0.2)	15 (2.5)	0.0001
Pericardiocentesis	12 (1.2)	8 (1.4)	0.82

Values are n (%) or mean ± SD.
MI = myocardial infarction.

CONCLUSIONS

In this single-center study, clinical and angiographic parameters predicting CTO-PCI procedural success were identified and included in a scoring model system using a backward stepwise approach. This model allows the identification of 4 subgroup score values corresponding to high, intermediate, low, and very low probability of CTO-PCI success. The increasing score values correlate with low probability of CTO-PCI success ranging from <50% to more than 80%. The CL-score outperformed the J-CTO score in predicting procedural success. The applicability of the score needs to be validated in other centers.

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PERSPECTIVES

WHAT IS KNOWN? Multiple nonrandomized studies reported the long-term clinical benefits of successful CTO-PCI compared with CTO-PCI failure. However, these results are limited in their application because it is difficult to predict the success of a CTO-PCI.

WHAT IS NEW? We report here the first predictive score of final procedural CTO-PCI success. This model seems to be applicable in centers where the retrograde/hybrid approach has not yet been implemented.

WHAT IS NEXT? Validation of this predictive model of CTO-PCI success in a population of patients treated using a hybrid approach is needed.

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